

Annual Progress Report #1 – Item 01D

Title: “Mesosphere-Stratosphere Coupling: Implications for Climate Variability and Trends”

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Papers published or submitted during Year 1 (1 July 2003 – 30 June 2004):

- 1) Baldwin, M.P., D.B. Stephenson, D.W.J. Thompson, T.J. Dunkerton, A.J. Charlton, A.O'Neill, Stratospheric memory and extended-range weather forecasts, *Science*, 301, 636-640, 2003.
- 1) Baldwin, M.P., and T.J. Dunkerton, The Solar Cycle and Stratosphere-Troposphere Dynamical Coupling, *Journal of Atmospheric and Solar-Terrestrial Physics*, submitted to the *Journal of Atmospheric and Solar-Terrestrial Physics*. Reviews were completed, and we are now revising the paper.
- 2) Baldwin, M.P., D.W.J. Thompson, E.F. Shuckburgh, W.A. Norton, N.P. Gillett, Weather from the stratosphere?, *Science* (Invited Perspective), 301, 317-318, 2003.
- 3) Charlton, A.J., A. O'Neill, D.B. Stephenson, W.A. Lahoz, M.P. Baldwin, Can knowledge of the state of the stratosphere be used to improve statistical forecasts of the troposphere?, *Quart. J. Royal Met. Soc.*, 129, 3205–3224, 2003.
- 4) Baldwin, M.P., Comment on “Tropospheric response to stratospheric perturbations in a relatively simple general circulation model” by Lorenzo M. Polvani and Paul J. Kushner. *Geophys. Res. Lett.*, Vol. 30 (15), 1812, doi:10.1029/2003GL017793, 2003.
- 5) Gillett, N.P., M.P. Baldwin, D.W.J. Thompson, E.F. Shuckburgh, W.A. Norton, J.L. Neu, “The role of the stratosphere in tropospheric climate” Report on the Workshop held in Whistler, British Columbia, Canada. 29 April to 2 May, 2003. SPARC Newsletter, July 2003.
- 6) Thompson, D.W.J., M.P. Baldwin, S. Solomon, Stratosphere-troposphere coupling during the 2002 major stratospheric warming in the Southern Hemisphere, *J. Atmos. Sci.*, in press, 2004.
- 7) Randel, W., et. al., Review paper: The SPARC Intercomparison of Middle Atmosphere Climatologies. *J. Climate*, 986-1003, 2004.

All of these papers and the book chapter are available in PDF format at <http://www.nwra.com/baldwin>.

Presentations and Meetings:

- 1) 3 presentations (1 invited) at IUGG Sapporo, Japan, July 2003.
- 2) Presentation at CNRS Paris, France, July 2003.
- 3) Presentation at University of Oxford, July 2003.
- 4) Presentation at University of Reading, July 2003.
- 5) Presentation at the British Met Office, August 2003.
- 6) Invited presentation at IAGU solar meeting, Prague, Czech Republic, September 2003.
- 7) Invited presentation at the SPARC Steering Group meeting in Frankfurt, Germany, September, 2004.
- 8) Invited presentation at the WCRP Task Force on Seasonal Prediction, Honolulu, November 2003.
- 9) Presentation at the AMS Annual Meeting, Seattle, January, 2004.
- 10) Invited colloquium at Colorado State University, March 2004.
- 11) Working Group Leader at the US Planning Meeting for International Heliophysical Year (IHY 2007), Sunspot, NM, April, 2004.
- 12) Invited presentation at the AGU Spring Meeting, Montreal, Canada, May 2004.
- 13) Invited presentation at "Challenges in the Climate Sciences," Blois, France, May 2004.

Tasks accomplished during the first year:

- 1) MPB was appointed to be the team leader for the "Stratosphere-Troposphere Dynamical Coupling" initiative for the World Climate Research Programme's SPARC Project.
- 2) MPB was appointed to the WCRP Task Force on Seasonal Prediction and attended the first meeting in Honolulu in November.
- 3) MPB was appointed to the US IHY 2007 Steering Committee.
- 4) We have obtained daily ECMWF ERA-40 reanalysis data for 1958-2001 (0.6 TB), including model levels to 0.1 hPa. We have made calculations of the annular mode index, zonal wind differences, and temperature differences.
- 5) We have also obtained a 50-year control run from NCAR's WACCM model, and a series of runs from GFDL's SKYHI model.

Analysis and interpretation:

A key aspect of this project is the establishment of a causal link from circulation anomalies in the lower mesosphere and stratopause region downward through the stratosphere to the troposphere. The observational link for "stratospheric" sudden warmings (which affect both the mesosphere and stratosphere) and surface climate is fairly clear. However, our understanding of the dynamics is incomplete. We have been making significant progress in the area of dy-

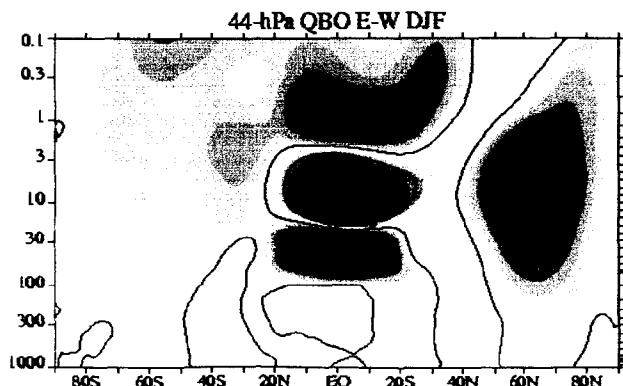
namical mechanisms by which circulation anomalies in the stratosphere affect the troposphere. Without establishing these dynamical linkages, we are left with only statistical relationships.

We are trying to understand the details and sequence of events that occur when a middle atmosphere (wind) anomaly propagates downward to near the tropopause. The wind anomaly could be caused by a warming or solar variations in the low-latitude stratopause region, or could have other causes. The observations show a picture that is consistent with a circulation anomaly that descends to the tropopause region, and can be detected as low as the mid-troposphere (in temperature). The surface pressure anomaly appears to be induced by dynamical processes in the upper troposphere—consistent with the mechanism described by Haynes and Shepherd [1989].

WCRP's Stratospheric Processes and their Role in Climate (SPARC) project is being reorganized around three themes, one of which is stratosphere-troposphere dynamical coupling. The SPARC Steering Group (at the 2003 meeting in Frankfurt) supported a meeting (similar to the Whistler meeting which we held in April/May 2003) in 2006. Part of this theme includes coupling to the mesosphere.

Processes near the stratopause in the tropics appear to be important precursors to the winter-time development of the northern polar vortex. However, the details remain elusive. It is possible that the new ECMWF ERA-40 dataset will aid in improving our understanding of this region and of the effects of solar processes. We have obtained the ECMWF ERA-40 data with 35 levels in the vertical (daily averages). In practical terms, these data are good to slightly above 1 hPa, but they are not useful at the 0.1 hPa level because the model has a sponge layer and 0.1 hPa is the top of the model. One surprising result obtained by Lesley Gray (Reading U.) is that our previous understanding of the QBO near the stratopause was not accurate. This may affect significantly our understanding of the process by which low-latitude wind anomalies in the lower mesosphere and upper stratosphere evolve through the winter and affect the polar vortex.

Recent published work by Lesley Gray, Katja Mathes, and others supports the idea that the stratopause region in the tropics is important for the seasonal development of middle atmosphere circulation anomalies during the winter. In the figure below, the difference in zonal winds is shown, between QBO east and west years (with the QBO defined at 44 hPa).



This figure was made using the ERA-40 data. The polar wind anomaly (blue) is of the same sign as the QBO anomaly, but also the stratopause anomaly. It may be that the stratopause anomaly, which depends on both the QBO and the timing of the SAO, is more important than the QBO in the lower stratosphere.

The JASTP paper is an overview for a Special Issue on the Prague Workshop. It is written for a general audience to understand that there is a mechanism that can communicate a solar signal (or any signal) near the stratopause down to Earth's surface.

The GRL comment compares Polvani and Kushner's [2002] simplified model results to real data. Much of the stratospheric influence that they see is also in the data. Polvani and Kushner, in their simple model, observed a dramatic northward shift in the position of the tropospheric subtropical jet when the middle atmosphere jet became very strong. This behavior was not seen in the observational data.

On decadal and longer timescales, there is a connection between trends in the middle atmosphere polar vortex and the surface annular modes. If the middle atmosphere circulation changes with ozone depletion or increasing greenhouse gases, those changes will likely be reflected in changes to surface climate.

Modeling studies, using stratosphere-troposphere GCMs, do not give consistent results about the future climate of the stratosphere or troposphere. Model predictions of future climate (with increasing greenhouse gases) do not agree as to whether the middle atmosphere polar vortex will strengthen or weaken. The timing of such influences within the seasonal cycle is also important (e.g., whether in early or late winter) and may eventually help to explain some of the disagreement between models [O'Sullivan and Dunkerton, 1994]. Even for models with a "proper" representation of stratosphere, results can be opposite. Shindell et al., [1999], for example, predicted a stronger, colder stratospheric polar vortex and increasing surface NAM index. In contrast, Kettleborough et al. [2003] found that the stratospheric polar vortex would become warmer and weaker (with $4\times\text{CO}_2$), with a more negative NAM index and a region of surface cooling at high latitudes. It is not yet possible to determine which scenario is more correct, but the answer has critical implications for climate and how society anticipates, and acts proactively towards, future climate change.

References

- Haynes, P. H., Shepherd, T. G., The importance of surface-pressure changes in the response of the atmosphere to zonally-symmetric thermal and mechanical forcing. *Q. J. Roy. Meteorol. Soc.*, 116, 1181–1208, 1989.
- Kettleborough J.A., L. J. Gray, N. P. Gillett, M. R. Allen, The response of stratospheric warmings to changing CO_2 concentrations, *Geophysical Research Abstracts*, Vol. 5, 08951, 2003 European Geophysical Society, 2003.
- O'Sullivan, D. J., and T. J. Dunkerton, Seasonal development of the extratropical qbo in a numerical model of the middle atmosphere, *J. Atmos. Sci.*, 51, 3706–3721, 1994.
- L.M. Polvani and P.J. Kushner: Tropospheric response to stratospheric perturbations in a relatively simple general circulation model, *Geophys. Res. Lett.*, 29, no. 7, 10.129/2001GL014284 (2002)

Shindell, D.T., R.L. Miller, G.A. Schmidt, and L. Pandalfo, Simulation of recent northern winter climate trends by greenhouse-gas forcing, *Nature*, 399, 452–455, 1999.

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